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Chemical Analyses of Soil Samples Collected from the Sandia National Laboratories, New Mexico Environs, 1993–2005

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Abstract

From 1993 through 2005, the Environmental Management Department of Sandia National Laboratories in Albuquerque, New Mexico (SNL/NM), has collected soil and sediment samples at numerous locations on-site, on the perimeter, and off-site for the purpose of determining potential impacts to the environs from operations at the Laboratories. These samples were submitted to an analytical laboratory for metal-in-soil analyses. Intercomparisons of these results were then made to determine if there was any statistical difference between on-site, perimeter, and off-site samples, or if there were year-to-year increasing or decreasing trends which indicated that further investigation may be warranted. This work provided the SNL Environmental Management Department with a sound baseline data reference against which to assess potential current operational impacts or to compare future operational impacts. In addition, it demonstrates the commitment that the Laboratories have to go beyond mere compliance to achieve excellence in its operations. This data is presented in graphical format with narrative commentaries on particular items of interest.

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Introduction

In order to establish a baseline for trace metals that exist in the soils of Sandia National Laboratories, New Mexico (SNL/NM), from 1993 through 2005, the Environmental Management Department at SNL/NM collected soil and sediment samples at numerous locations on-site, on the perimeter, and off-site for the purpose of determining potential impacts to the environs from operations at the Laboratories. The locations are shown in Figures 1 and 2, and tabulated in Tables 1, 2, and 3. Samples were submitted to an analytical laboratory for metal-in-soil analyses (target analyte list [TAL] metals). Similar to the soil samples, sediment samples were also collected at several locations. Sediment samples sometimes can be used to determine if aggregation or concentration of contaminants in runoff can help identify trends earlier, or if they otherwise may go undetected completely. These locations are also indicated in the Tables and Figures as well and are not plotted separately.

These soil and sediment results were compared to determine if there was any statistical difference between on-site, perimeter, and off-site samples, or if there were year-to-year increasing or decreasing trends which indicated that further investigation may be warranted to ascertain the cause of the observed anomaly (Shyr, Haaker, and Herrera 1998). In some cases, the ratio between two or more elements can be used to determine if the observed concentrations are natural or anthropogenic (Hooper 2004). When more than one distribution is observed in these plots, the data are assumed to be heterogeneous (i.e., a separate source is associated with each distribution) (McLish 1994). Comparisons of these soil and sediment samples were made by media, location, and constituent following each sampling campaign, but the summary data has been pooled in this report to save space. This work provided the SNL Environmental Management Department with a sound baseline data reference against which to compare future operational impacts. In addition, it demonstrates the commitment that the Laboratories have to go beyond mere compliance, but to also achieve excellence in its operations. This data is presented in graphical format, with narrative commentaries on particular items of interest.

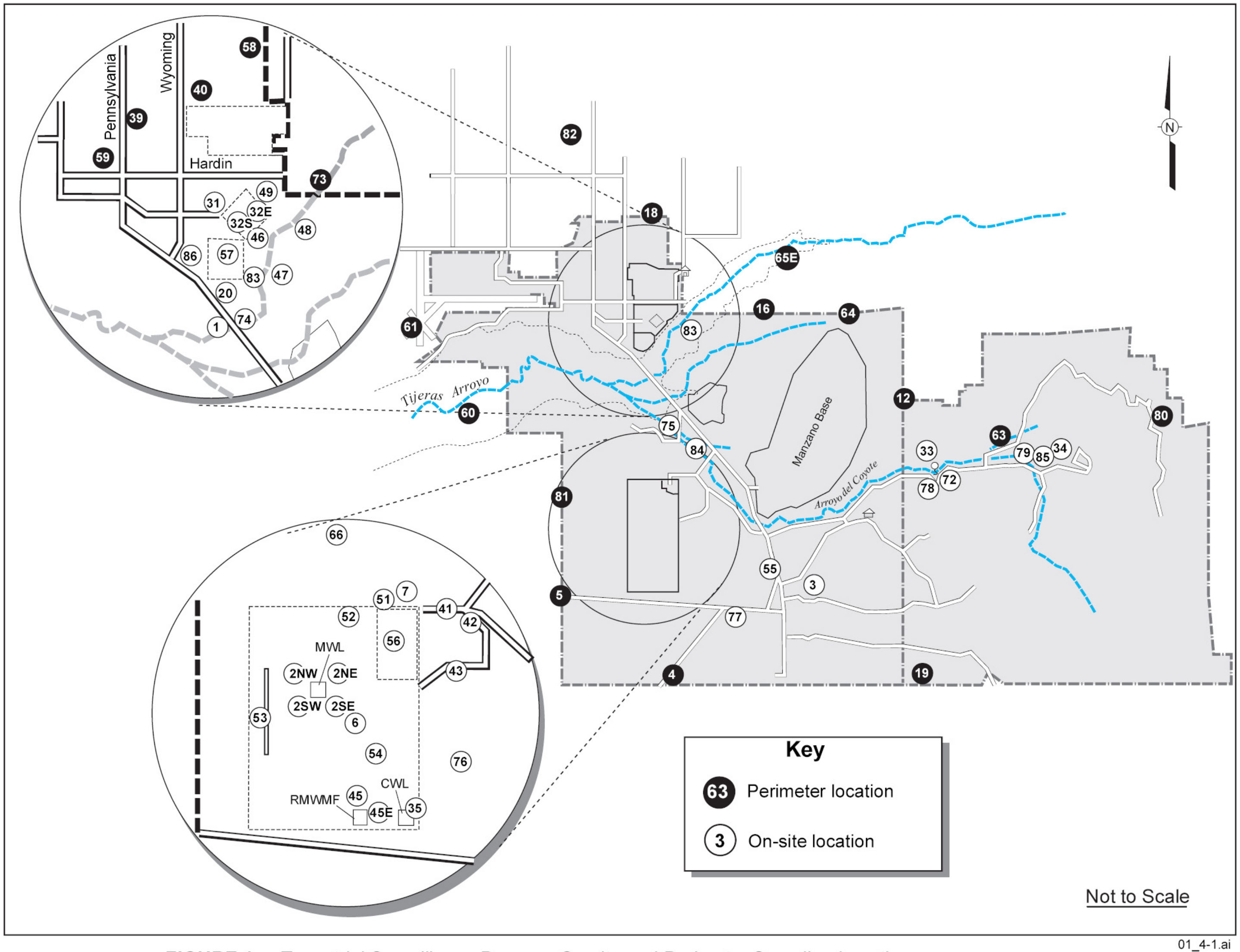

FIGURE 1. Terrestrial Surveillance Program On-site and Perimeter Sampling Locations
On-site locations are within areas of SNL/NM operations. Perimeter locations are located both on and off KAFB property.

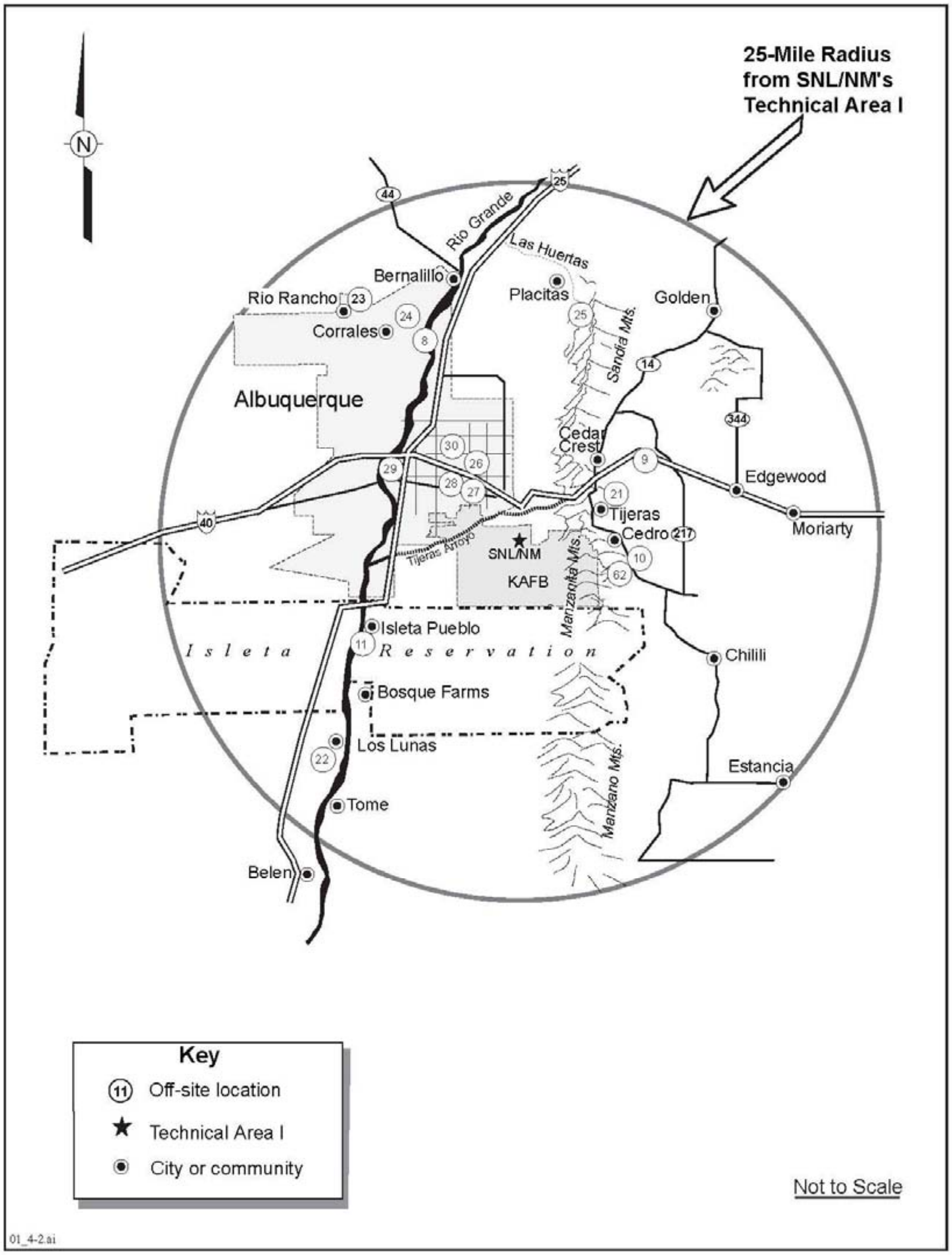

FIGURE 2. Terrestrial Surveillance Program Off-site Sampling Locations

TABLE 1. On-site Terrestrial Surveillance Locations and Sample Types

Location Number	Sampling Location	Soil	Sediment
1	Pennsylvania Ave.	X	
2NW	Mixed Waste Landfill (MWL) (northwest)	X	
2NE	MWL (northeast)	X	
2SE	MWL (southeast)	X	
2SW	MWL (southwest)	X	
3	Coyote Canyon Control	X	
6	Tech Area (TA) III (east of water tower)	X	
7	Unnamed Arroyo (north of TA-V)	X	
20	TA-IV (southwest) (KAFB Skeet Range)	X	
32S	TA-II, Bldg. 935 (south bay door)	X	
33	Coyote Springs	X	
34	Lurance Canyon Burn Site	X	
35	Chemical Waste Landfill (CWL)	X	
41	TA-V (northeast fence)	X	
42	TA-V (east fence)	X	
43	TA-V (southeast fence)	X	
45	Radioactive and Mixed Waste Management Facility (RMWMF), TA-III (northwest corner)	X	
46	TA-II (south corner)	X	
49	Near the Explosive Components Facility (ECF)	X	
51	TA-V (north of culvert)	X	
52	TA-III, northeast of Bldgs. 6716 and 6717	X	
53	TA-III south of long sled track	X	
54	TA-III, Bldg. 6630	X	
55	Large Melt Facility (LMF), Bldg. 9939	X	
56	TA-V, Bldg. 6588 (west corner)	X	X
57	TA-IV, Bldg. 970 (northeast corner)	X	
66	KAFB Facility	X	
76	Thunder Range (north)	X	
77	Thunder Range (south)	X	
78	School House Mesa	X	
79	Arroyo del Coyote (up-gradient)		X
83	Tijeras Arroyo GW Well		X
84	Storm Water Monitoring Point (SWMP)-10		X
85	Arroyo del Coyote Cable Site		X

TABLE 2. Perimeter Terrestrial Surveillance Locations and Sample Types

	Sampling Location	Soil	Sediment
4	Isleta Reservation Gate	X	
5	McCormick Gate	X	
12	Northeast Perimeter	X	
16	Four Hills	X	
19	USGS Seismic Center Gate	X	
58	North KAFB Housing	X	
59	Zia Park (southeast)	X	
60	Tijeras Arroyo (down-gradient)	X	X
61	Albuquerque International Sunport (west)	X	
63	No Sweat Boulevard	X	
64	North Manzano Base	X	
65E	Tijeras Arroyo, east (up-gradient)	X	X
80	Madera Canyon	X	
81	KAFB West Fence	X	
82	Commissary	X	

TABLE 3. Off-site Terrestrial Surveillance Locations and Sample Types

Location Number	Sampling Location	Soil	Sediment
8	Rio Grande, Corrales Bridge (up-gradient)	X	X
9	Sedillo Hill, I-40 (east of Albuquerque)	X	
10	Oak Flats	X	
11	Rio Grande, Isleta Pueblo (down-gradient)	X	X
25	Placitas Fire Station	X	
62	East resident	X	

Results of the soil and sediment samples were evaluated using probability plotting, which provided a visual representation of the entire data set for all locations and for all times sampled. If the results were similar, or fit a linear distribution when plotted on logarithmic or log-probability scales, then the results were attributable to natural origin. Summary statistics for each element was imbedded in each plot. If any samples indicated concentrations greater than expected from the rest of the sample distribution, further evaluation was conducted to determine if SNL/NM facility operations were possibly responsible for the observed result. Table 4 provides various reference values for metals-in-soil. Applicable NMED Screening Levels (if available) for Industrial and Residential use are indicated on the graphs.

Appendix A contains a detailed description of the mechanics of log-normal plotting. Appendix B contains the plots of the soil/sediment data, sorted alphabetically by analyte name. Associated with each plot presented are the summary statistics for each analyte.

Table 4. Various Reference Values for Metals-in-Soil

	NM Soil Concentrations[1]		NMED Soil Screening Levels[2]		US Soil Concentrations[3]	
Analyte	**Lower Limit**	**Upper Limit**	**Residential**	**Industrial**	**Lower Limit**	**Upper Limit**
Aluminum	5000	100000	74000	100000	4500	100000
Antimony	0.2	1.3	30	92	0.25	0.6
Arsenic	2.5	19	4	17	1	93
Barium	230	1800	5200	15000	20	1500
Beryllium	1	2.3	150	440	0.04	2.54
Cadmium	ND	11	70	190	0.41	0.57
Calcium	600	320000	n/a	n/a	n/a	n/a
Chromium	7.6	42	230	660	7	1500
Cobalt	2.1	11	4500	13000	3	50
Copper	2.1	30	2800	8500	3	300
Iron	1000	100000	23000	69000	5000	50000
Lead	7.8	21	400	1000	10	70
Magnesium	300	100000	n/a	n/a	n/a	n/a
Manganese	30	5000	7800	14000	20	3000
Mercury	0.01	0.06	7	20	0.02	1.5
Molybdenum	1	6.5	380	1200	0.8	3.3
Nickel	2.8	19	1500	4400	5	150
Potassium	1900	63000	n/a	n/a	n/a	n/a
Selenium	0.2	0.8	380	1200	0.1	4
Silica (Silicon)	150000	440000	n/a	n/a	24000	368000
Silver	0.5	5	380	1200	0.2	3.2
Sodium	500	100000	n/a	n/a	n/a	n/a
Strontium	88	440	37000	89000	7	1000
Thallium	n/a	n/a	6	18	0.02	2.8
Titanium	910	4000	n/a	n/a	20	1000
Vanadium	15	94	530	1600	0.7	98
Zinc	18	84	23000	69000	13	300

ND = not detectable
n/a = not available
(1) Dragun, James, A. Chiasson, *Elements in North American Soils*, 1991, Hazardous Materials Control Resources Institute, (Used San Juan Basin, A Horizon to determine values).
(2) NMED Soil Screening Levels (SSL), New Mexico Environmental Department Hazardous Waste Bureau and Ground Water Quality Bureau Voluntary Remediation Program, *Technical Background Document for Development of Soil Screening Levels*, NMED 2000
(3) US Soil Surface Concentrations
Kabata-Pendias, A., Pendias, H., CRC, *Trace Elements in Soils and Plants*, 2nd Edition, 1992

Summary

Soil and sediment samples have been collected from 1993 through 2005 at SNL/NM as one means of monitoring for the potential effects on the environment of facility operations at the Laboratories. The year-to-year results of this sampling effort are reported in the Annual Site Environmental Report (ASER, SNL 2005a). With the exception of a few locations, the data indicate that SNL/NM operations have made no significant impact to existing concentration of TAL metal in surface soil or sediment.

The only significant exception was noted at sampling location #20, immediately west of Technical Area IV (TA-IV). Here, elevated levels of As, Sb and Pb were detected. As it turns out, the As, Sb and Pb did not originate from SNL/NM operations, but coincidentally from the nearby Skeet Range operated by the Kirtland Air Force Base (KAFB) for many years. The Skeet Range has now been remediated and is no longer used (Montgomery-Watson 2001). The New Mexico Environment Department determined that this remediation was sufficient for No Further Action (Lundstrom 2003). Furthermore, comprehensive analysis of the data collected from this location corroborates that the low levels of residual As, Sb, and Pb at this location present no future risk to human health or the environment (SNL 2005b).

Appendix A - Data Analysis

The data in this report is presented in the form of log-normal probability plots. Such plots are useful tools for conveniently cataloguing and evaluating large amounts of data, as well as providing a first approximation of the similarity (or differences) of the data. The basis for using log-normal plotting is experience which has shown that large quantities of environmental data (many similar analyte/media combinations) yield a straight line when plotted on a log-probability or logarithmic scale (Miller 1977). The presumption of log-normal distribution is never a bad presumption and is never worse than the presumption of arithmetic-normal (Michels 1971). Because the data is represented graphically, the mean, standard deviation, expected upper limits, and any abnormalities can be readily determined visually (Waite 1975).

Characteristics of special importance in the use of log-normal plots are linearity (denoting data from a common population), standard geometric deviation ($\sigma_{g,}$ an indicator of variability or range), and geometric mean (X_g). The usit of slope in a log-normal plot involves a logarithmic increment. Thus, the standard deviation is a multiplier of the geometric mean (Michels 1971).The values for σ_g and X_g can be obtained from the graphs by the ratio of the 84%/50% intercepts and the 50% intercepts, respectively (Miller 1977). Linearity of the graph implies that any potential SNL/NM contribution to the observed concentration is indistinguishable from regional levels of the element. Anomalous results (potentially attributable to SNL/NM operations) must necessarily occur at a higher concentration than would be expected from regional distributions. For convenience, summary statistics for each element was imbedded in each plot. Included in this list is the Upper Tolerance Limit (UTL), which is defined as:

$$95^{th}\text{ UTL} = \bar{X} + K*S$$

Where UTL = Upper Tolerance Limit
X = Sample Arithmetic Mean
S = Sample Standard Deviation
K = One-sided normal tolerance factor

Values for K are commonly determined from tables such as those provided by Lieberman (Leiberman 1958). A typical value of K equal to 1.763 was assigned, which is for sample size of n = 500. The sample size for each element ranged from 500-1100. This UTL can be used to estimate a level above which a sample result may not be attributable to naturally occurring "background" levels of the element.

Whenever a particular results appears elevated (on the log-normal plot) compared to the expected concentration based on the population comprised of all the other locations, further investigation to determine if SNL/NM operations are potentially responsible may include (but should not be limited to) the following:

- What is the geographical location of the sample? Is there a detectable pattern to the anomalous observation or is the sample from an area in close proximity to a facility which has the potential for release of the analyte or contaminant?
- Does the location of the sample(s) show elevated levels for other analytes or for the results obtained from the same location in previous years?
- If several locations appear to be elevated, is there a particular year that had the elevated results? How did these compare to perimeter or off-site sample results?

As can be observed in many of the graphs, data at the lower end of the range frequently "falls off" in a manner that suggests that these results do not belong in the distribution being plotted, or are otherwise anomalous. However, in almost all instances, these results represent reported values that were at the extreme lower limit of the analytical method employed at the time of analysis. This is not atypical, since the plotted values do not include the analytical uncertainty or method detection level (MDL) for a given result. Also, the MDL changes (frequently becomes better) over time as the state-of-the-art for analytical science improves, and the aggregated data may include data that actually has a range of MDLs, which only becomes an artifact if the given analyte's concentration is near the MDL. In several of the plots, many of the same reported values appear as a "flat line". These values are typically the "less than" values reported by the laboratory when the analyte was not otherwise detected.

Appendix B contains the plots of the soil/sediment data, sorted alphabetically by analyte name. Any noteworthy anomalies in the plots are discussed by notes within the given plot. Associated with each plot presented in Appendix B are the summary statistics and NMED Screening Levels for each analyte.

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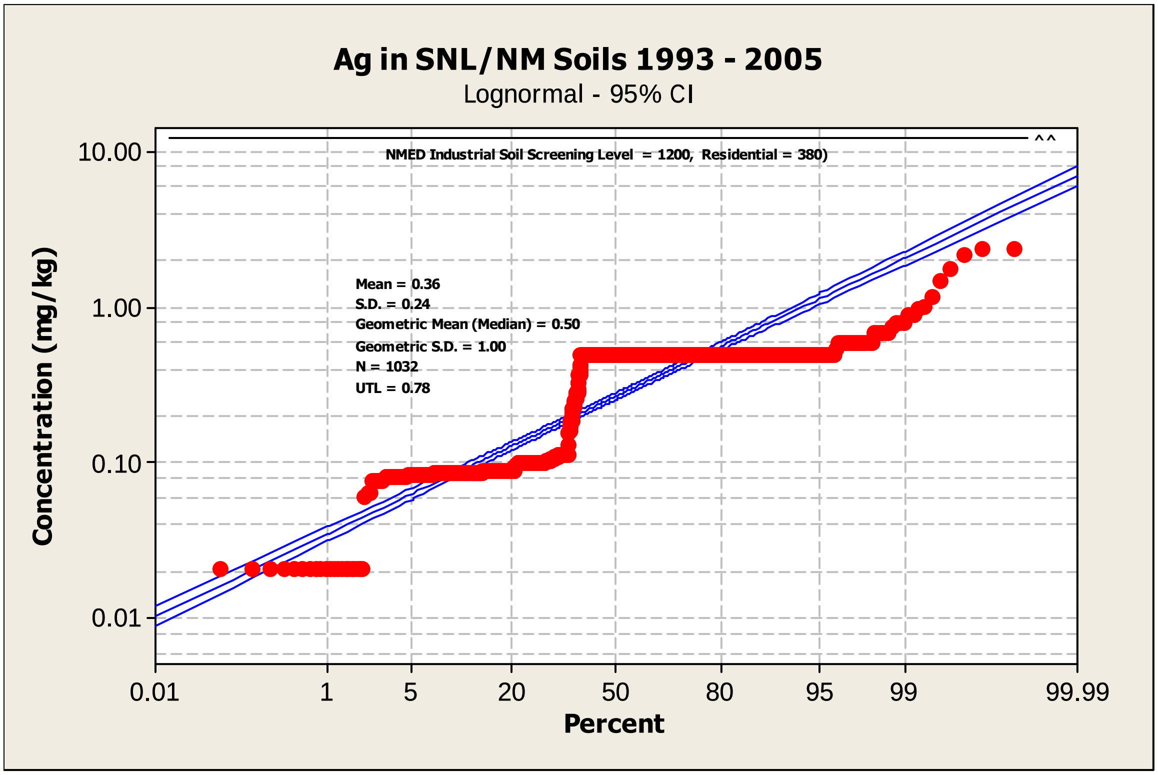
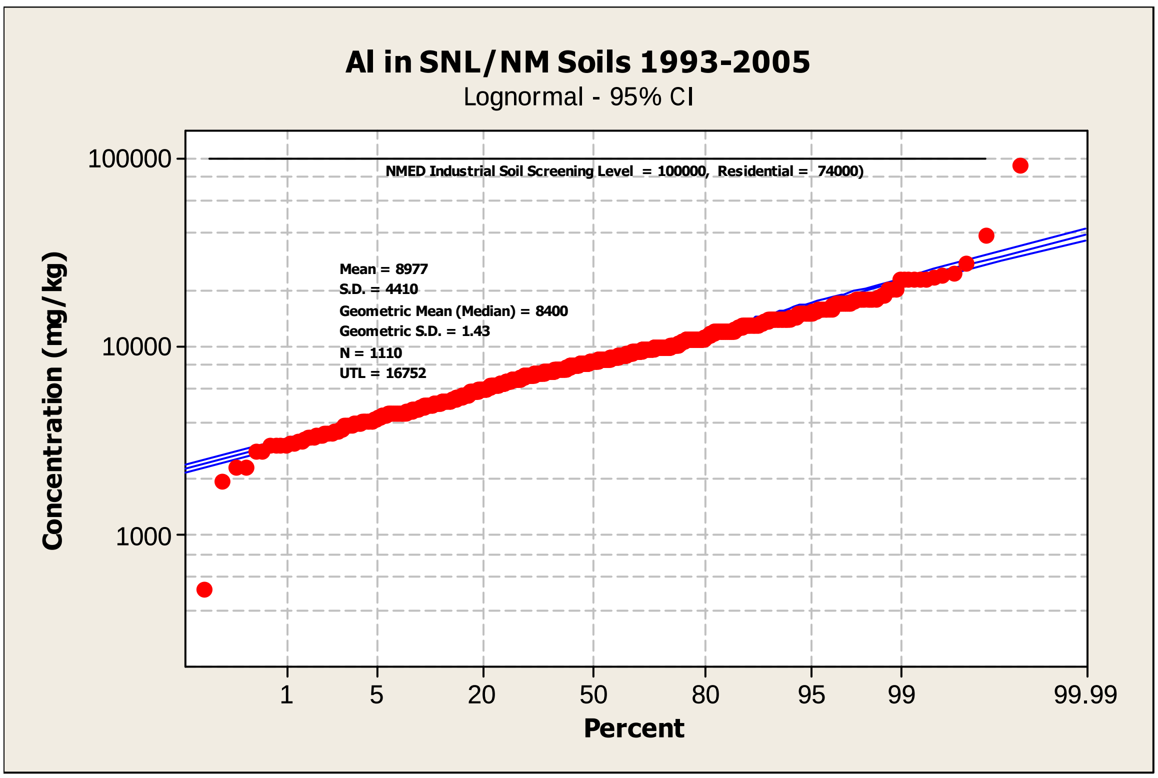
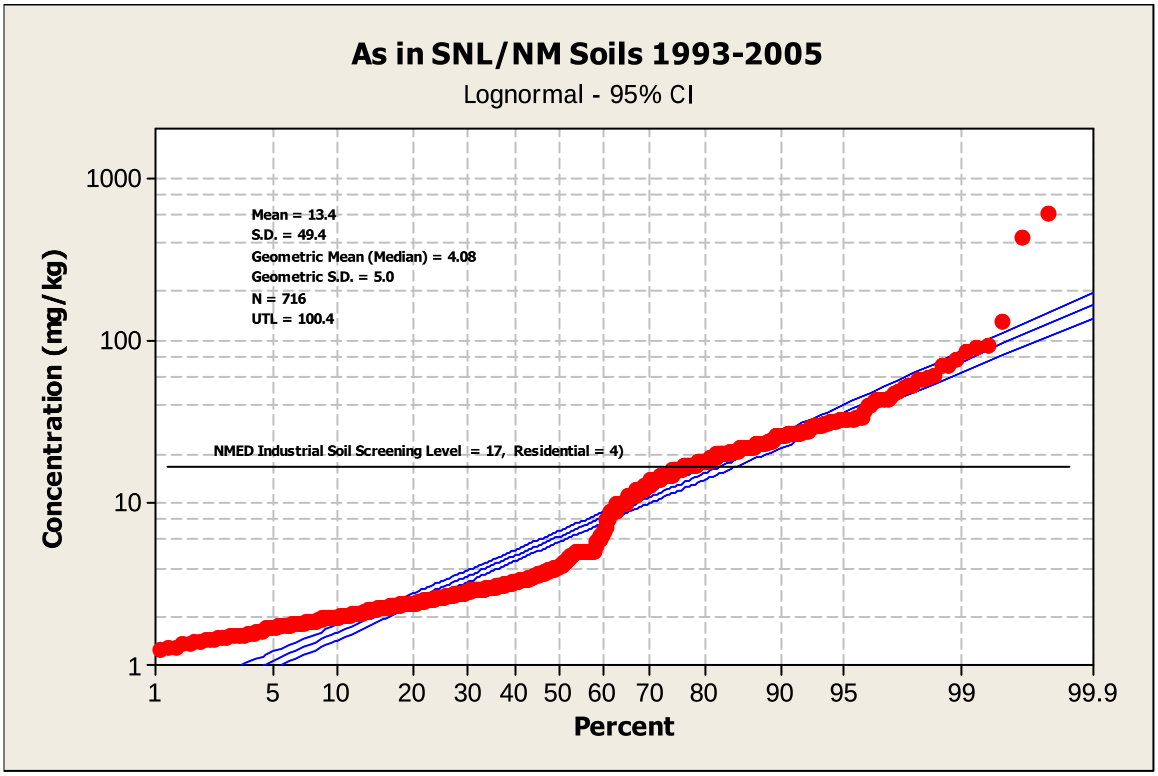
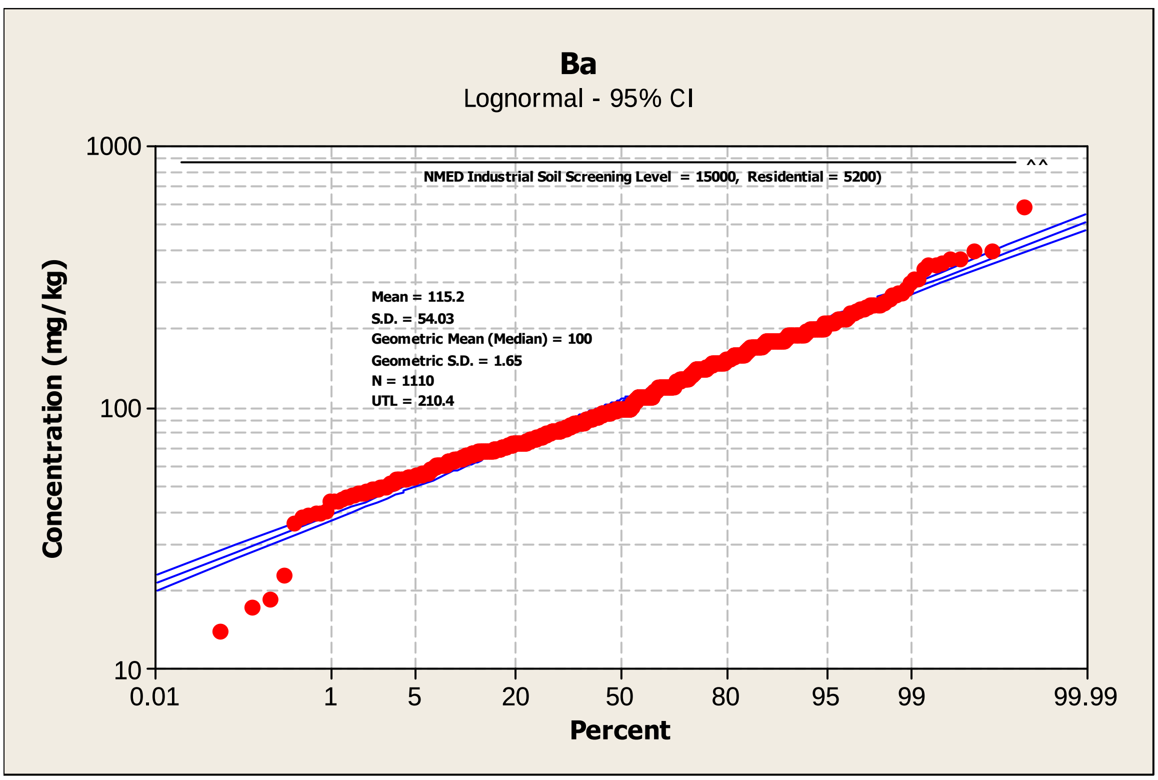
Appendix B – TAL Metals in Soil in the SNL/NM Environs



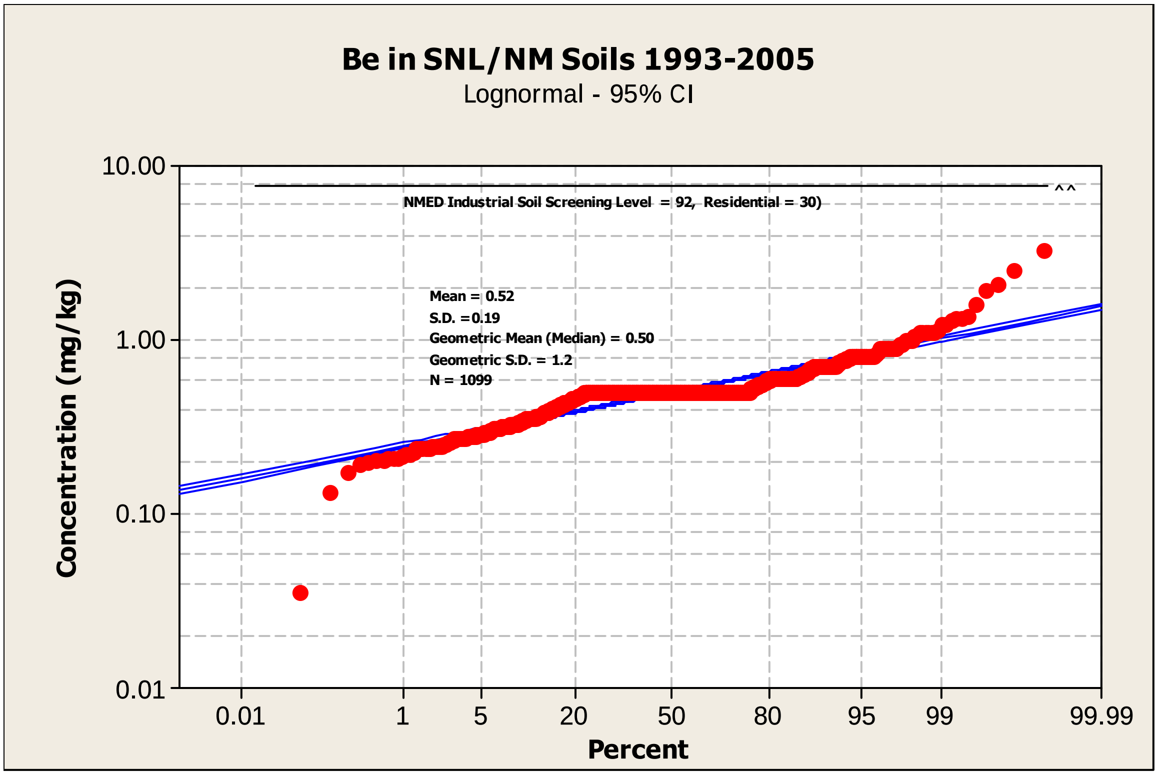


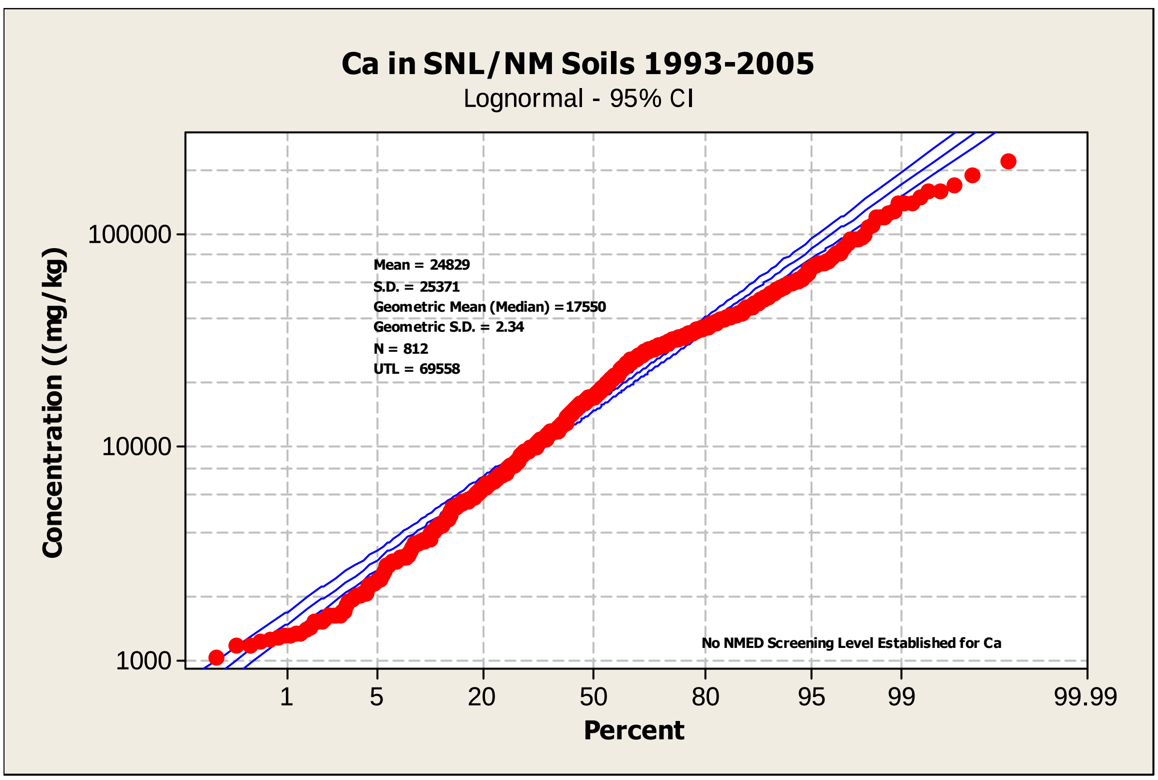


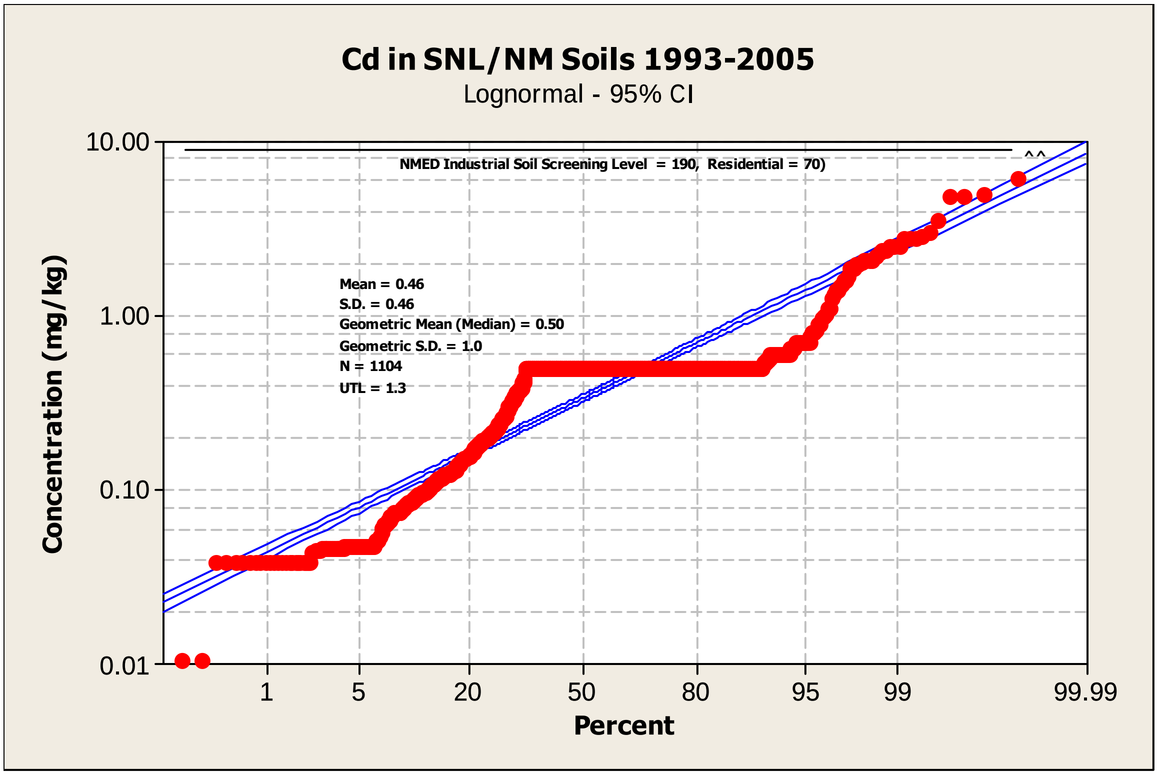
As in SNL/NM Soils 1993-2005
Lognormal - 95% CI
Mean = 13.4
S.D. = 49.4
Geometric Mean (Median) = 4.08
Geometric S.D. = 5.0
N = 716
UTL = 100.4
NMED Industrial Soil Screening Level = 17, Residential = 4)
Concentration (mg/kg)
1000
100
10
1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
Percent

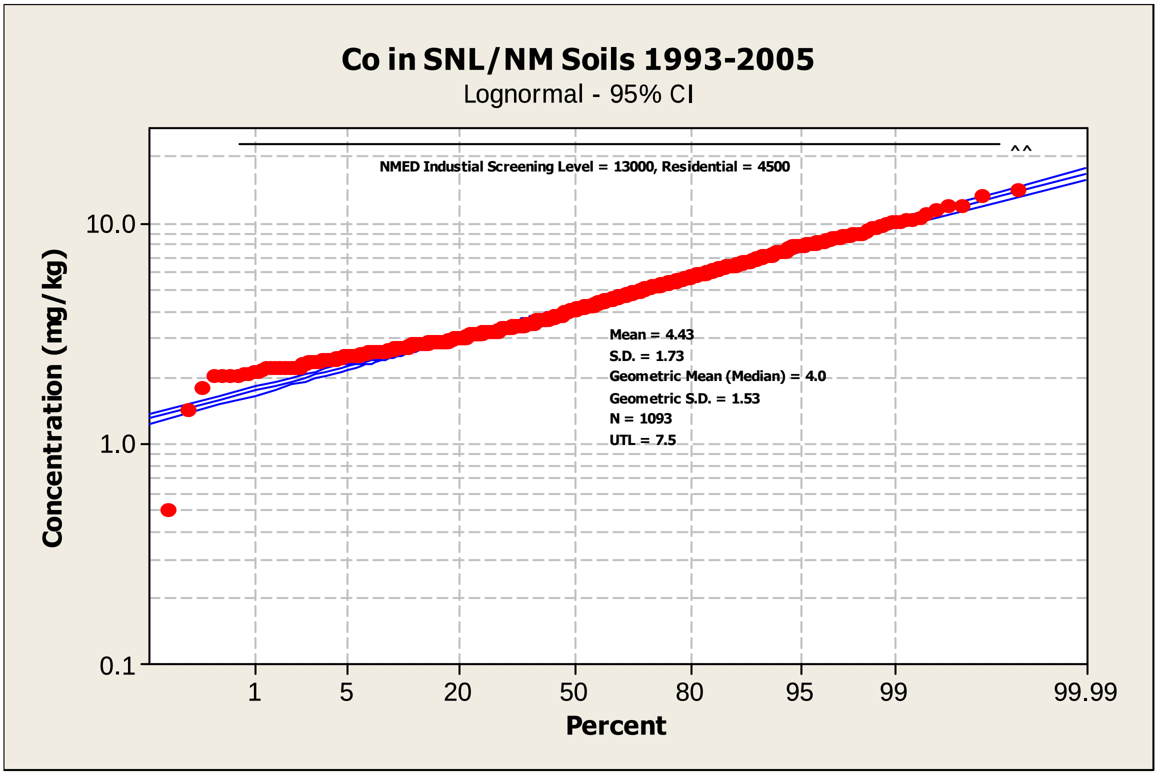


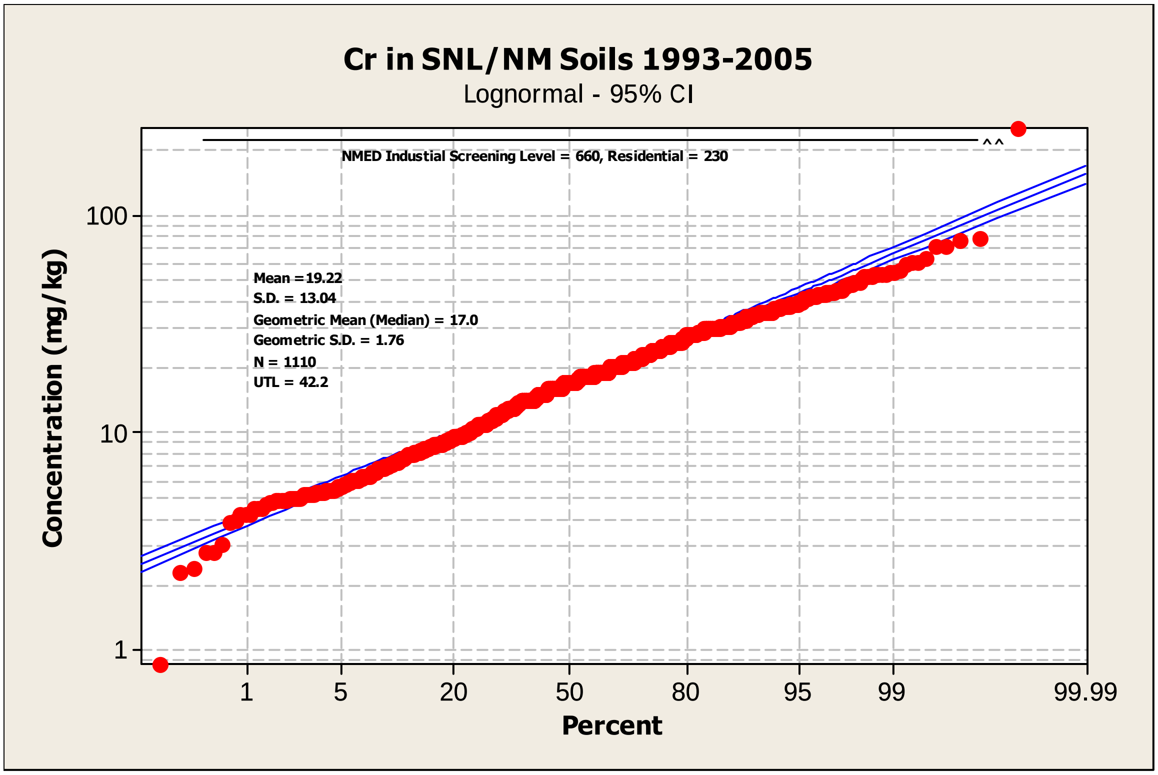
Ba
Lognormal - 95% CI
NMED Industrial Soil Screening Level = 15000, Residential = 5200)
^^
Mean = 115.2
S.D. = 54.03
Geometric Mean (Median) = 100
Geometric S.D. = 1.65
N = 1110
UTL = 210.4
Concentration (mg/kg)
1000
100
10
0.01
1
5
20
50
80
95
99
99.99
Percent

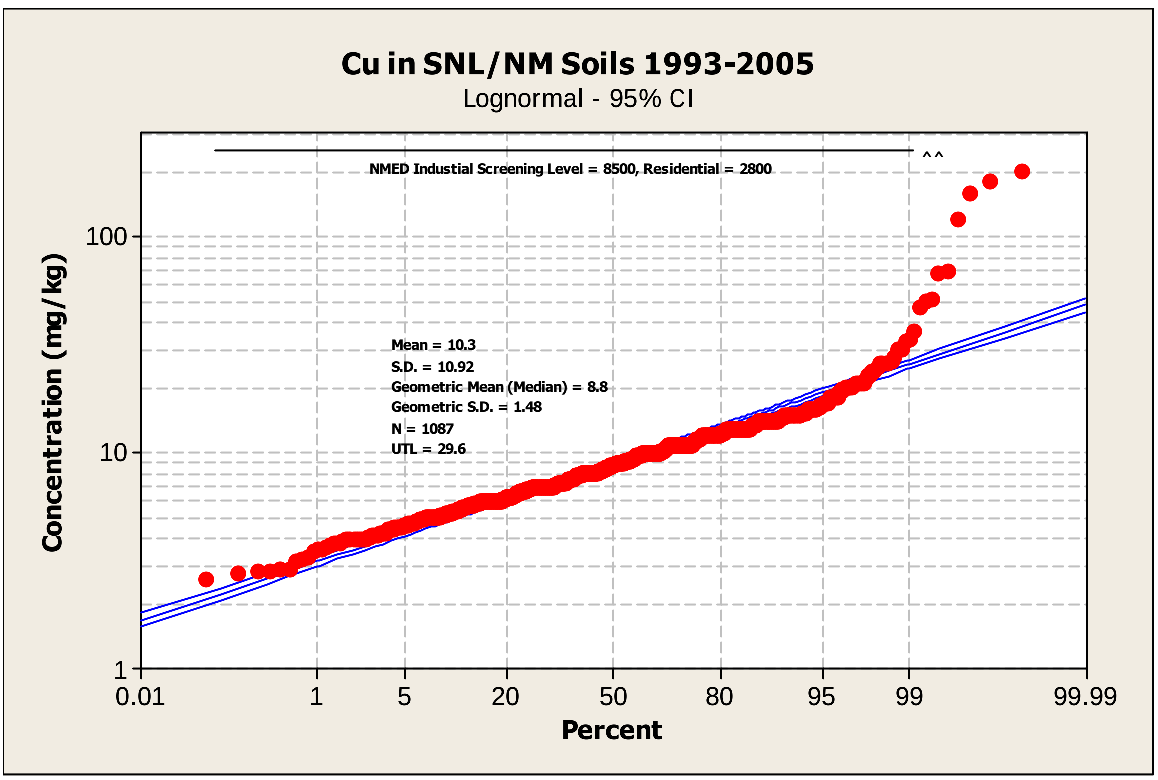

Be in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industrial Soil Screening Level = 92, Residential = 30)
Mean = 0.52
S.D. =0.19
Geometric Mean (Median) = 0.50
Geometric S.D. = 1.2
N = 1099
Concentration (mg/kg)
10.00
1.00
0.10
0.01
0.01
1
5
20
50
80
95
99
99.99
Percent

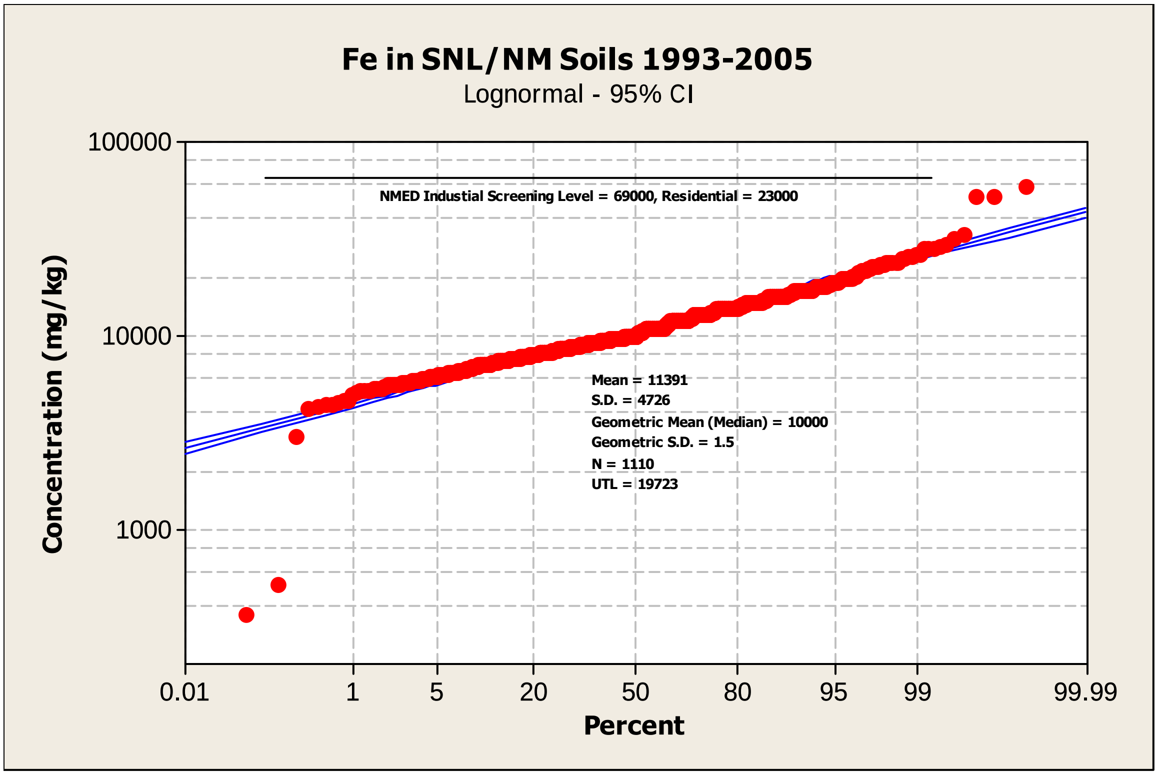

Ca in SNL/NM Soils 1993-2005
Lognormal - 95% CI
Mean = 24829
S.D. = 25371
Geometric Mean (Median) =17550
Geometric S.D. = 2.34
N = 812
UTL = 69558
No NMED Screening Level Established for Ca
Concentration ((mg/kg)
100000
10000
1000
1
5
20
50
80
95
99
99.99
Percent

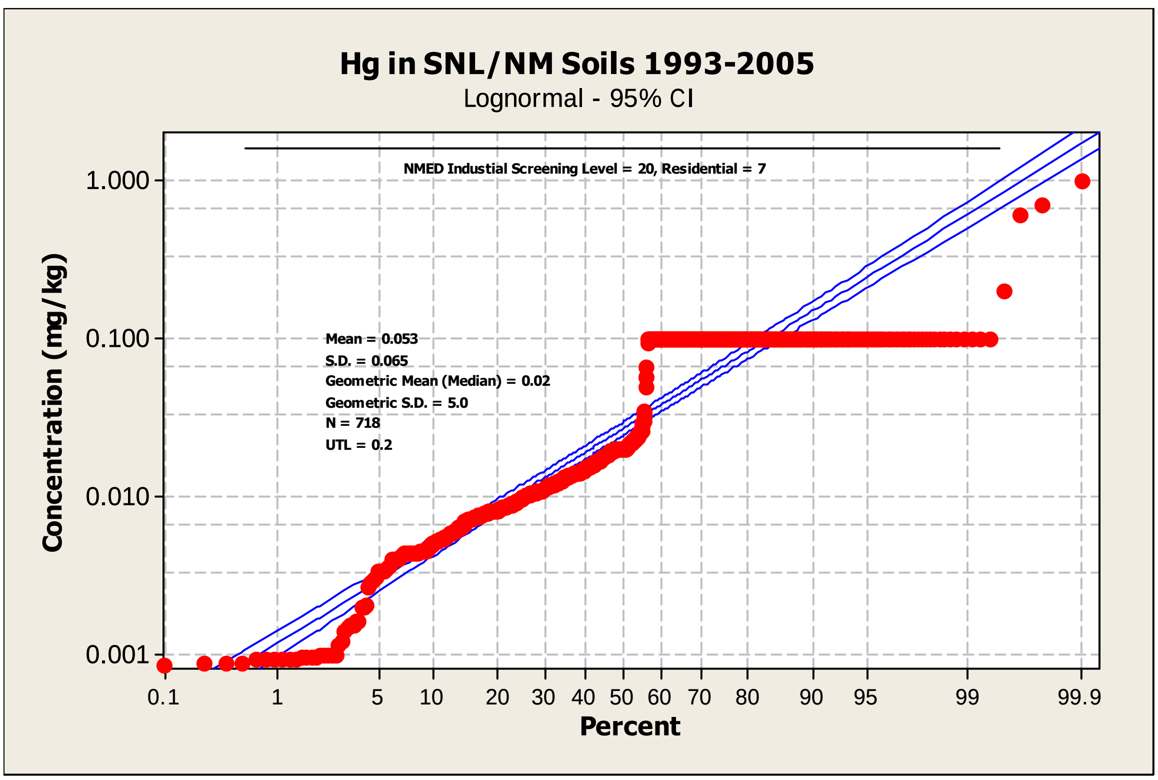

Cd in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industrial Soil Screening Level = 190, Residential = 70)
^^
Mean = 0.46
S.D. = 0.46
Geometric Mean (Median) = 0.50
Geometric S.D. = 1.0
N = 1104
UTL = 1.3
Concentration (mg/kg)
10.00
1.00
0.10
0.01
1
5
20
50
80
95
99
99.99
Percent

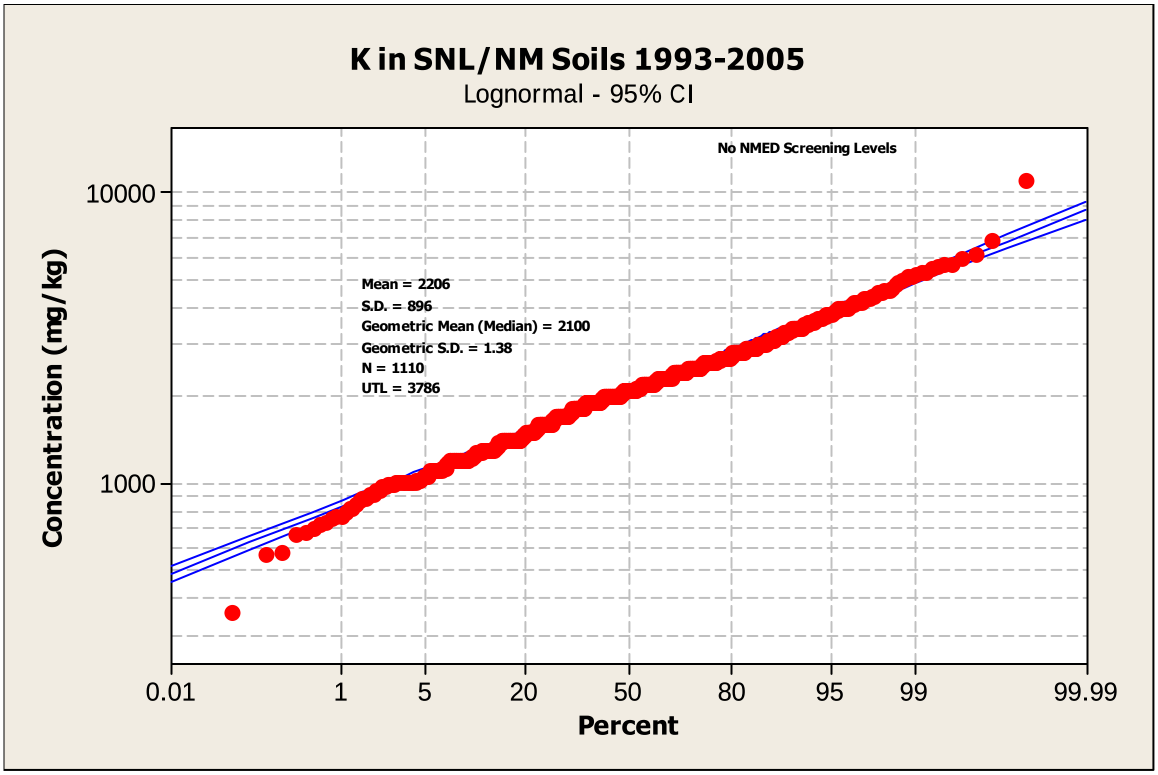

Co in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 13000, Residential = 4500
^^
Mean = 4.43
S.D. = 1.73
Geometric Mean (Median) = 4.0
Geometric S.D. = 1.53
N = 1093
UTL = 7.5
Concentration (mg/kg)
10.0
1.0
0.1
1
5
20
50
80
95
99
99.99
Percent

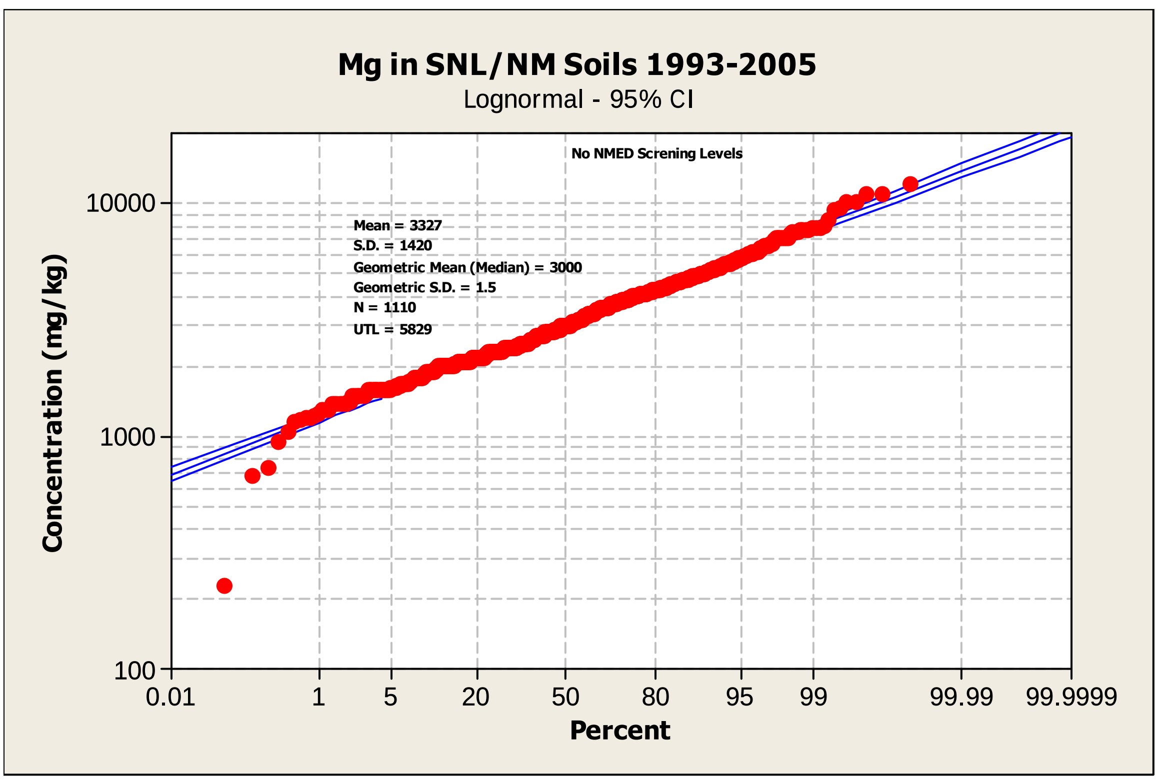

Cr in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 660, Residential = 230
Mean = 19.22
S.D. = 13.04
Geometric Mean (Median) = 17.0
Geometric S.D. = 1.76
N = 1110
UTL = 42.2
Concentration (mg/kg)
100
10
1
1
5
20
50
80
95
99
99.99
Percent

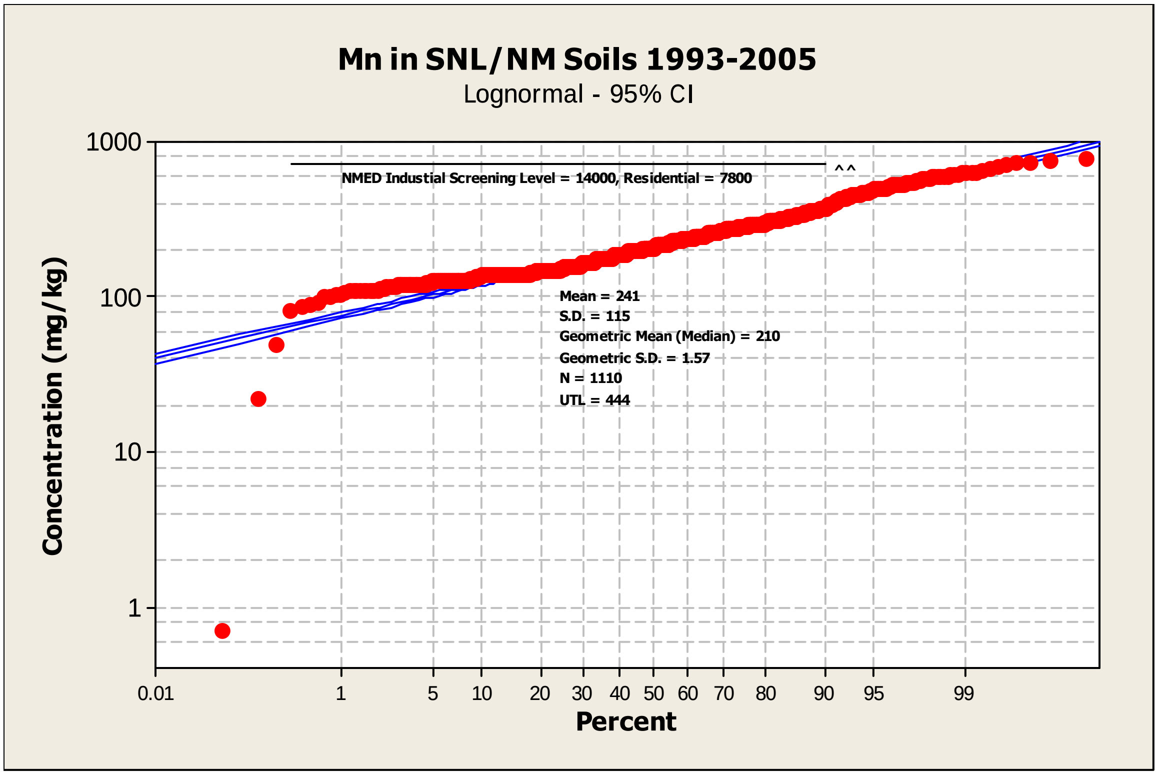

Cu in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 8500, Residential = 2800
Mean = 10.3
S.D. = 10.92
Geometric Mean (Median) = 8.8
Geometric S.D. = 1.48
N = 1087
UTL = 29.6
Concentration (mg/kg)
100
10
1
0.01
1
5
20
50
80
95
99
99.99
Percent

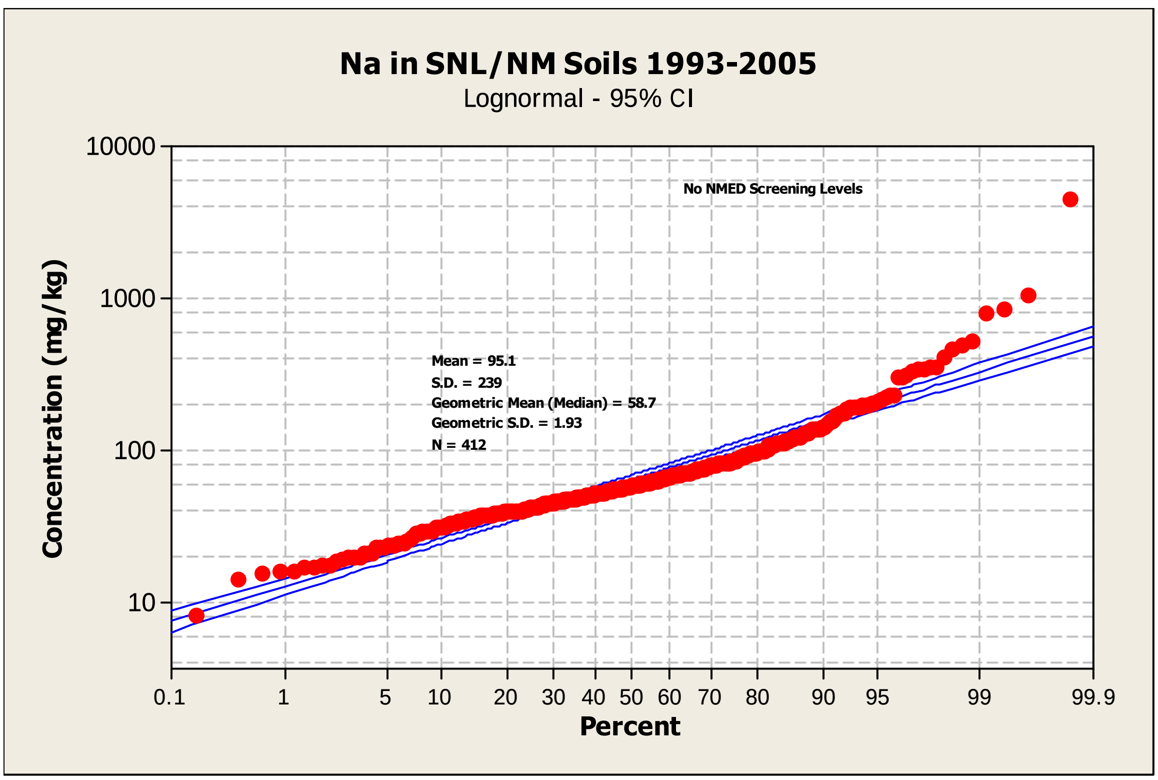

Fe in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 69000, Residential = 23000
Mean = 11391
S.D. = 4726
Geometric Mean (Median) = 10000
Geometric S.D. = 1.5
N = 1110
UTL = 19723
Concentration (mg/kg)
100000
10000
1000
0.01
1
5
20
50
80
95
99
99.99
Percent

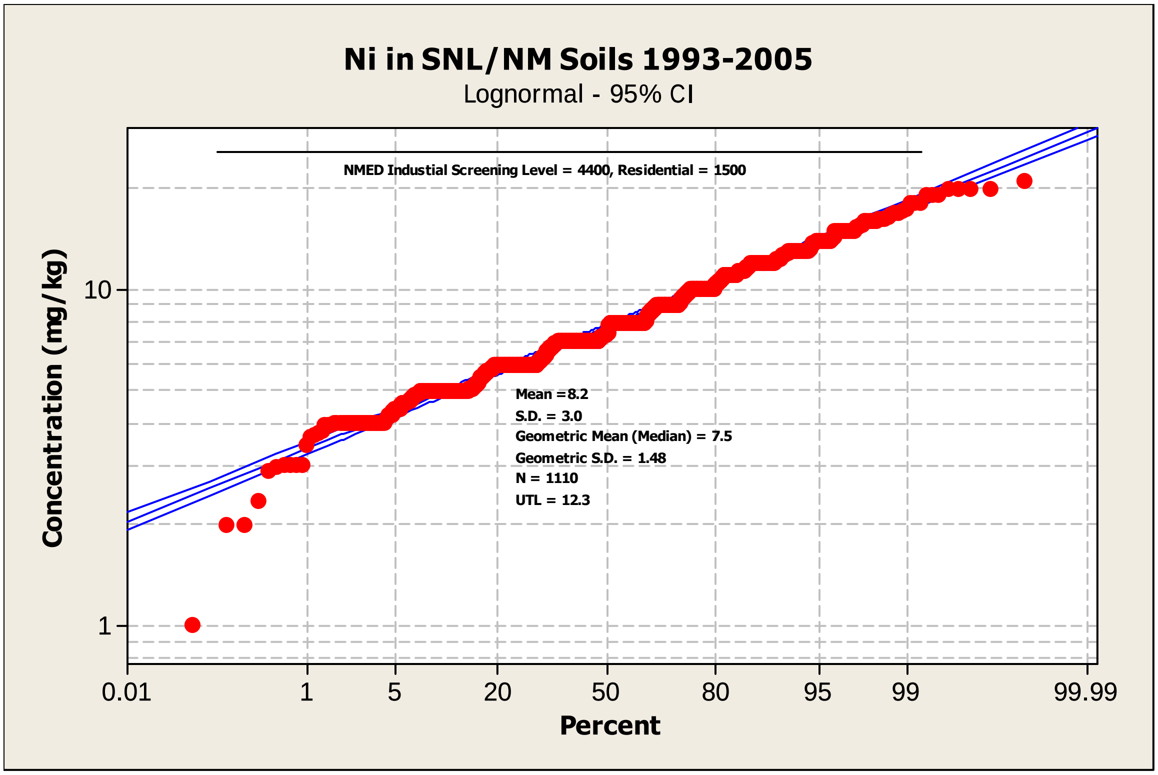

Hg in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 20, Residential = 7
Mean = 0.053
S.D. = 0.065
Geometric Mean (Median) = 0.02
Geometric S.D. = 5.0
N = 718
UTL = 0.2
Concentration (mg/kg)
1.000
0.100
0.010
0.001
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
Percent

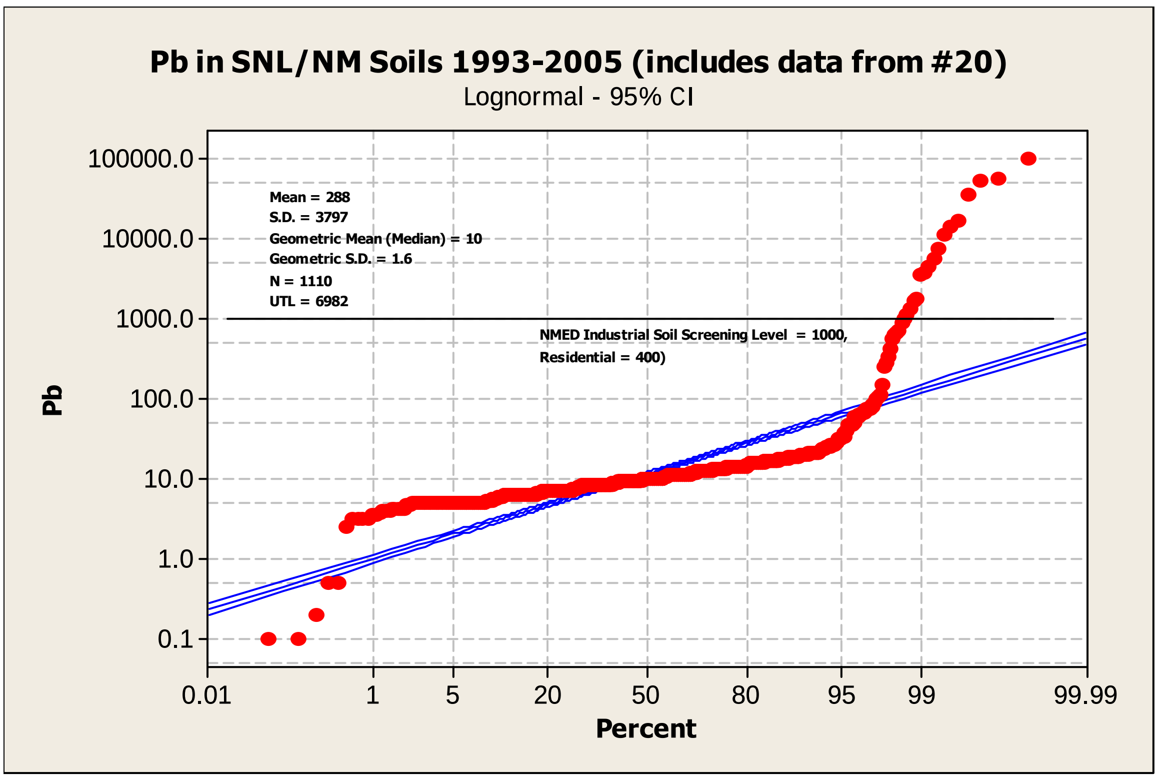

K in SNL/NM Soils 1993-2005
Lognormal - 95% CI
No NMED Screening Levels
Mean = 2206
S.D. = 896
Geometric Mean (Median) = 2100
Geometric S.D. = 1.38
N = 1110
UTL = 3786
Concentration (mg/kg)
10000
1000
0.01
1
5
20
50
80
95
99
99.99
Percent

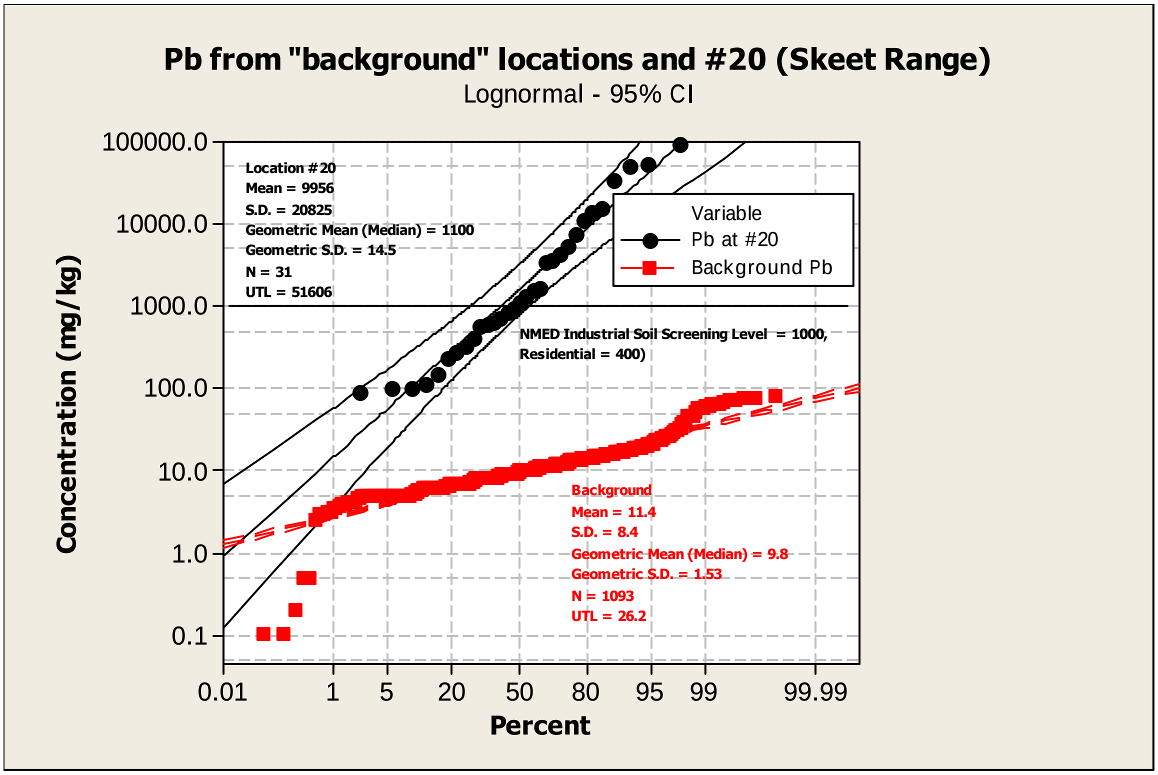

Mg in SNL/NM Soils 1993-2005
Lognormal - 95% CI
No NMED Screning Levels
Mean = 3327
S.D. = 1420
Geometric Mean (Median) = 3000
Geometric S.D. = 1.5
N = 1110
UTL = 5829
Concentration (mg/kg)
10000
1000
100
0.01
1
5
20
50
80
95
99
99.99
99.9999
Percent


Mn in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 14000, Residential = 7800
^^
Mean = 241
S.D. = 115
Geometric Mean (Median) = 210
Geometric S.D. = 1.57
N = 1110
UTL = 444
Concentration (mg/kg)
1000
100
10
1
0.01
1
5
10
20
30
40
50
60
70
80
90
95
99
Percent

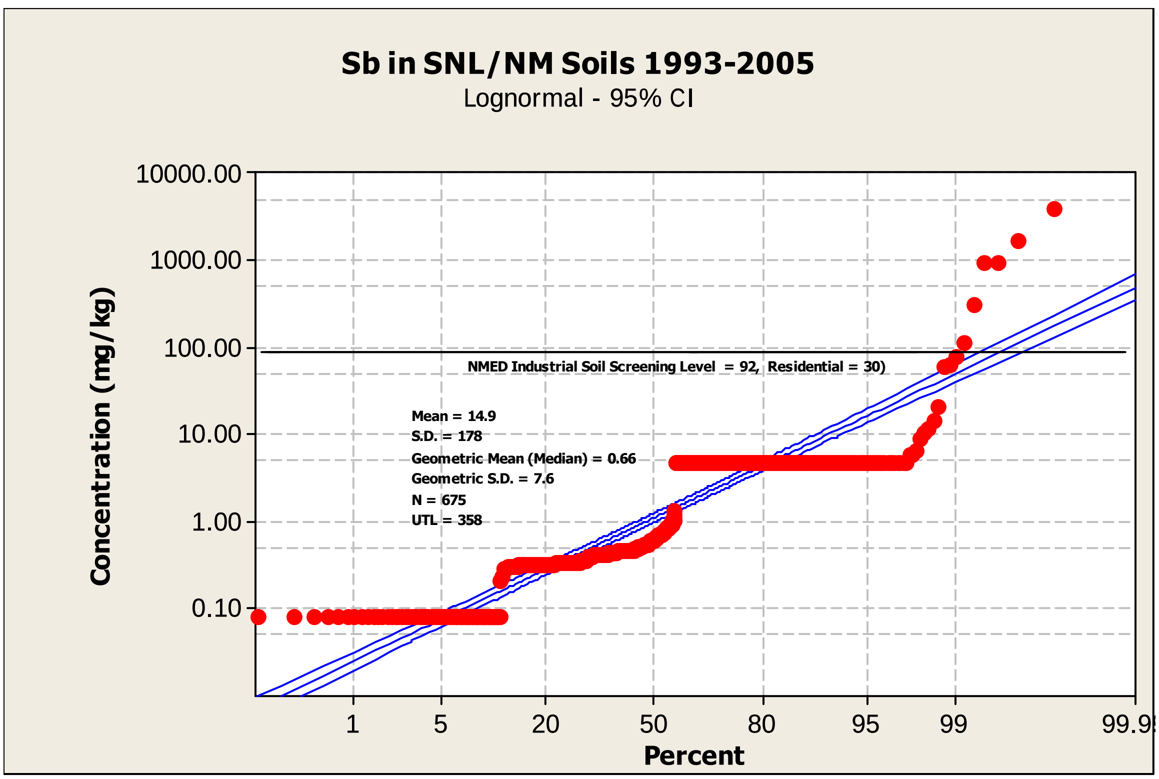

Na in SNL/NM Soils 1993-2005
Lognormal - 95% CI
No NMED Screening Levels
Mean = 95.1
S.D. = 239
Geometric Mean (Median) = 58.7
Geometric S.D. = 1.93
N = 412
Concentration (mg/kg)
10000
1000
100
10
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
Percent


Ni in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 4400, Residential = 1500
Mean =8.2
S.D. = 3.0
Geometric Mean (Median) = 7.5
Geometric S.D. = 1.48
N = 1110
UTL = 12.3
Concentration (mg/kg)
10
1
0.01
1
5
20
50
80
95
99
99.99
Percent

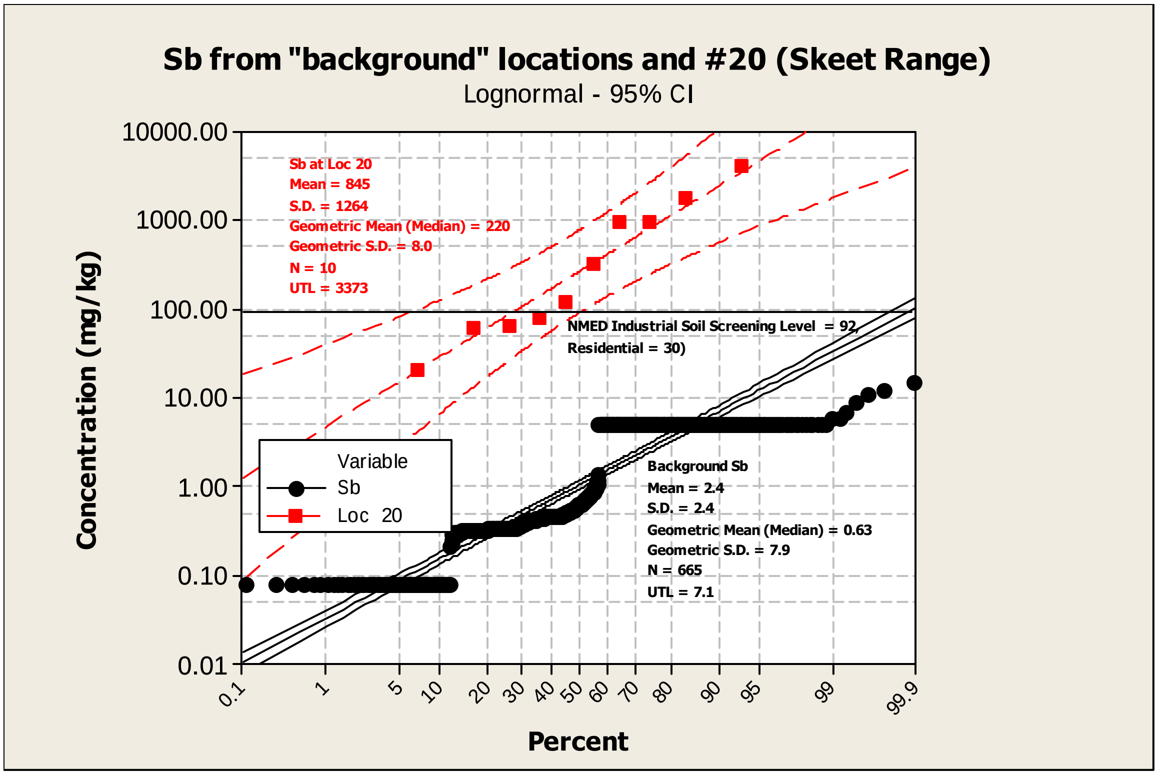

Pb in SNL/NM Soils 1993-2005 (includes data from #20)
Lognormal - 95% CI
Mean = 288
S.D. = 3797
Geometric Mean (Median) = 10
Geometric S.D. = 1.6
N = 1110
UTL = 6982
NMED Industrial Soil Screening Level = 1000,
Residential = 400)
Pb
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0.01
1
5
20
50
80
95
99
99.99
Percent



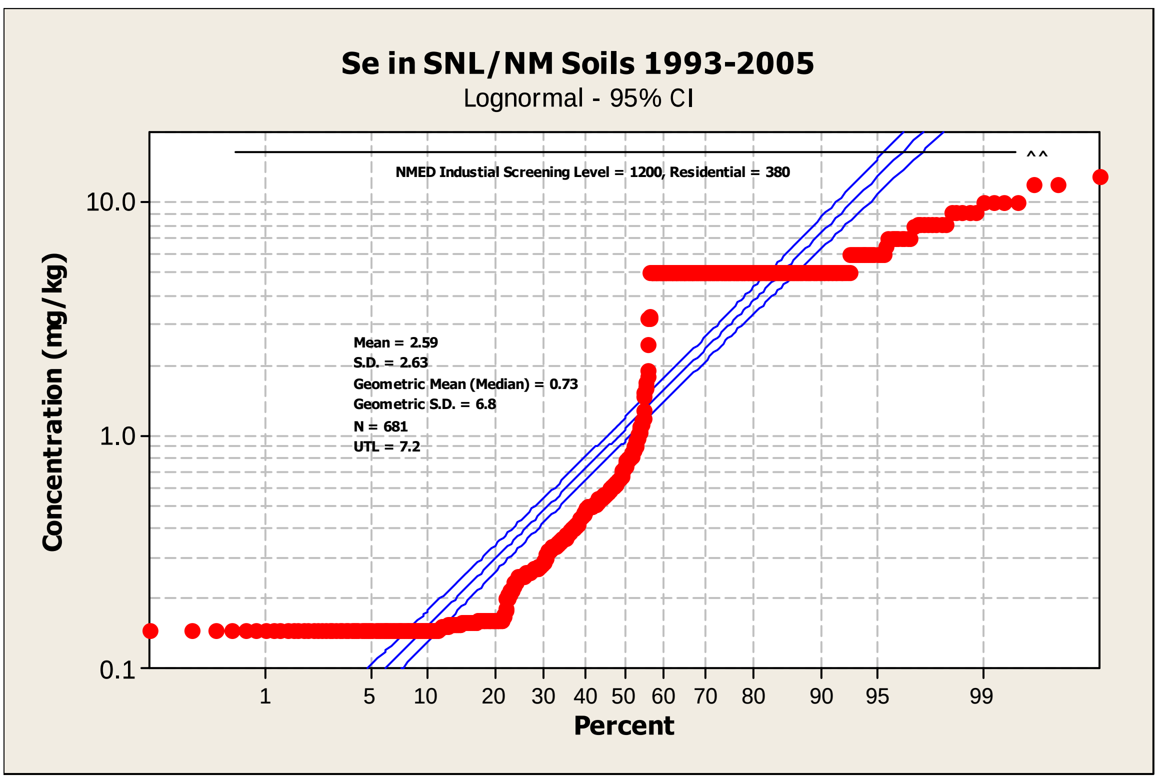
Pb from "background" locations and #20 (Skeet Range)
Lognormal - 95% CI
Location #20
Mean = 9956
S.D. = 20825
Geometric Mean (Median) = 1100
Geometric S.D. = 14.5
N = 31
UTL = 51606
Variable
Pb at #20
Background Pb
NMED Industrial Soil Screening Level = 1000, Residential = 400)
Background
Mean = 11.4
S.D. = 8.4
Geometric Mean (Median) = 9.8
Geometric S.D. = 1.53
N = 1093
UTL = 26.2
Concentration (mg/kg)
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0.01
1
5
20
50
80
95
99
99.99
Percent



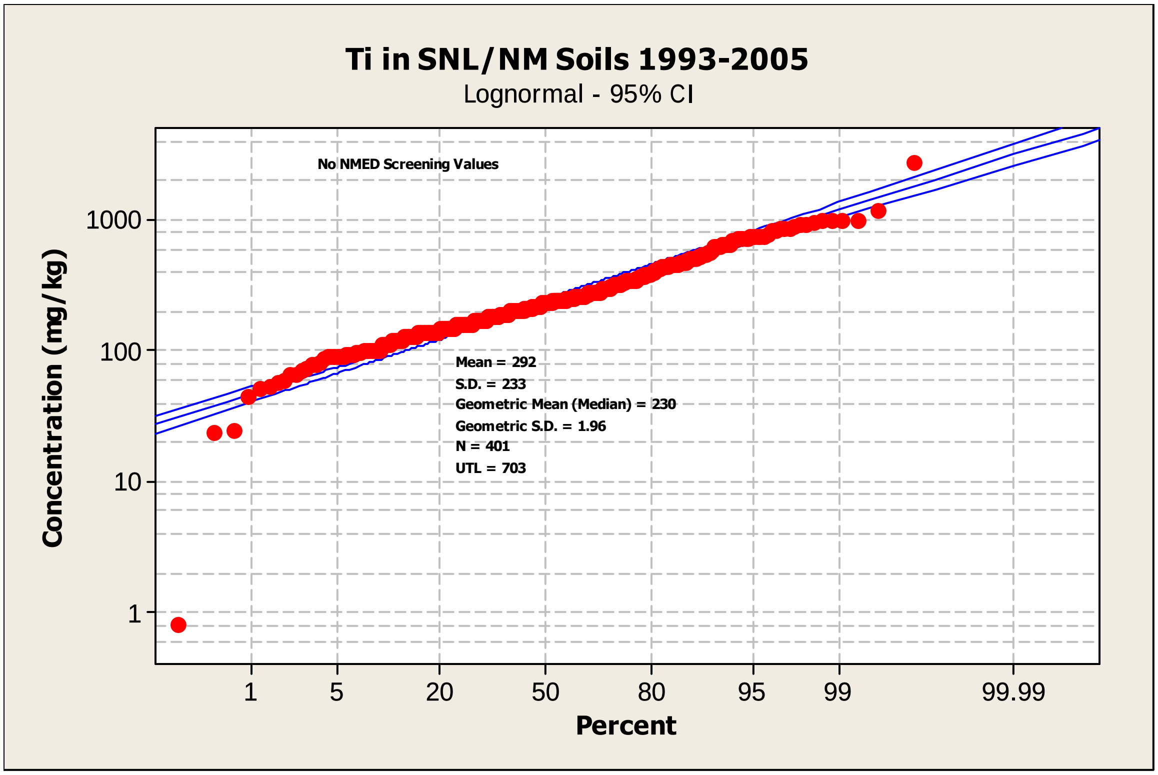
Sb in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industrial Soil Screening Level = 92, Residential = 30)
Mean = 14.9
S.D. = 178
Geometric Mean (Median) = 0.66
Geometric S.D. = 7.6
N = 675
UTL = 358
Concentration (mg/kg)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
5
20
50
80
95
99
Percent

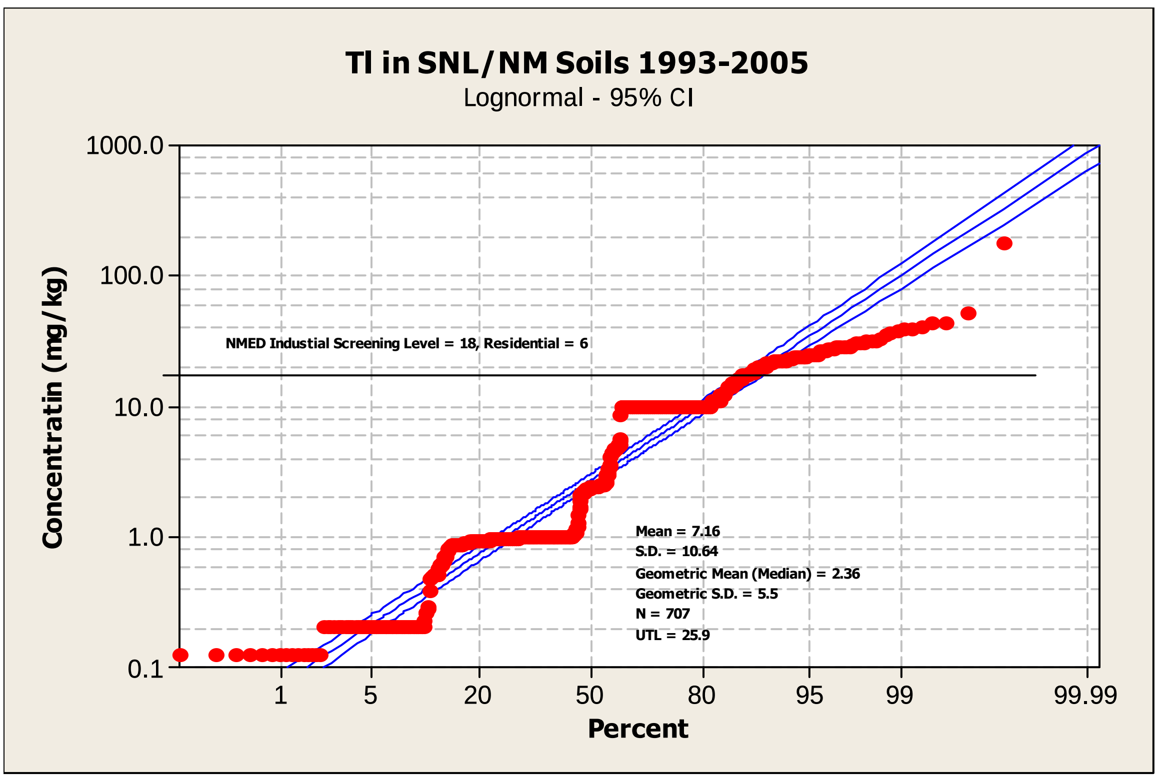


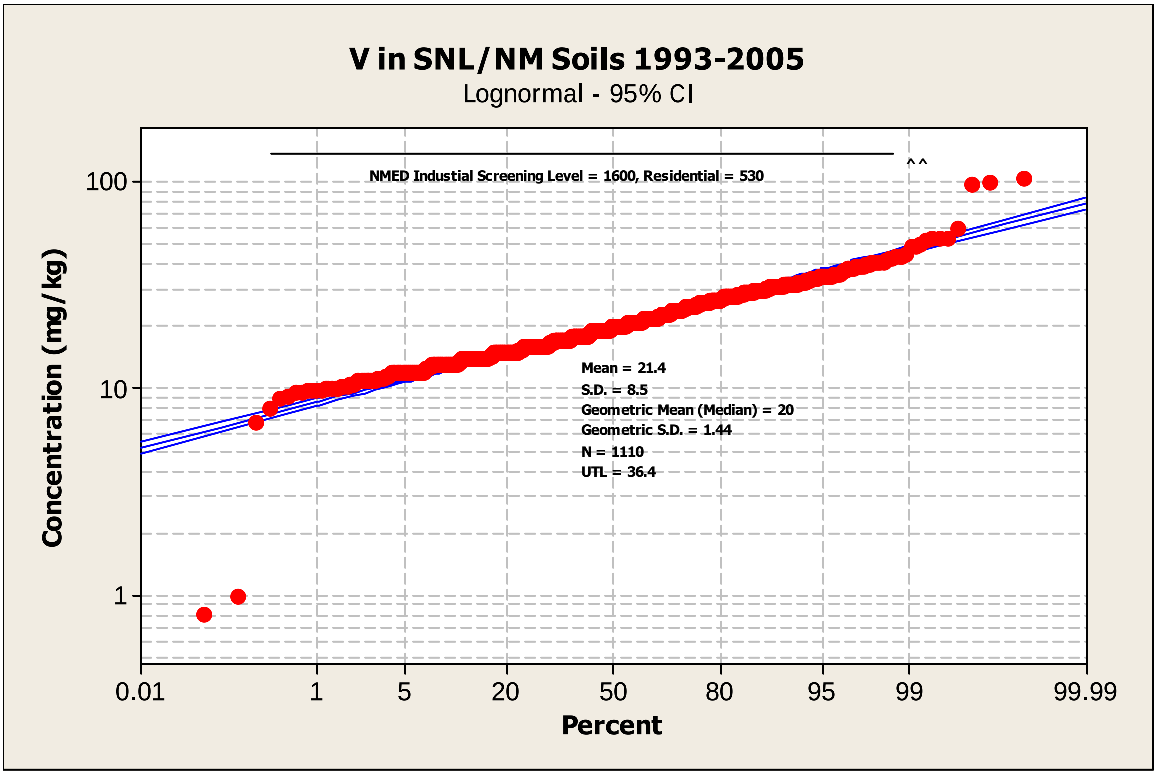
Sb from "background" locations and #20 (Skeet Range)
Lognormal - 95% CI
Sb at Loc 20
Mean = 845
S.D. = 1264
Geometric Mean (Median) = 220
Geometric S.D. = 8.0
N = 10
UTL = 3373
NMED Industrial Soil Screening Level = 92,
Residential = 30)
Variable
Sb
Loc 20
Background Sb
Mean = 2.4
S.D. = 2.4
Geometric Mean (Median) = 0.63
Geometric S.D. = 7.9
N = 665
UTL = 7.1
Concentration (mg/kg)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
Percent

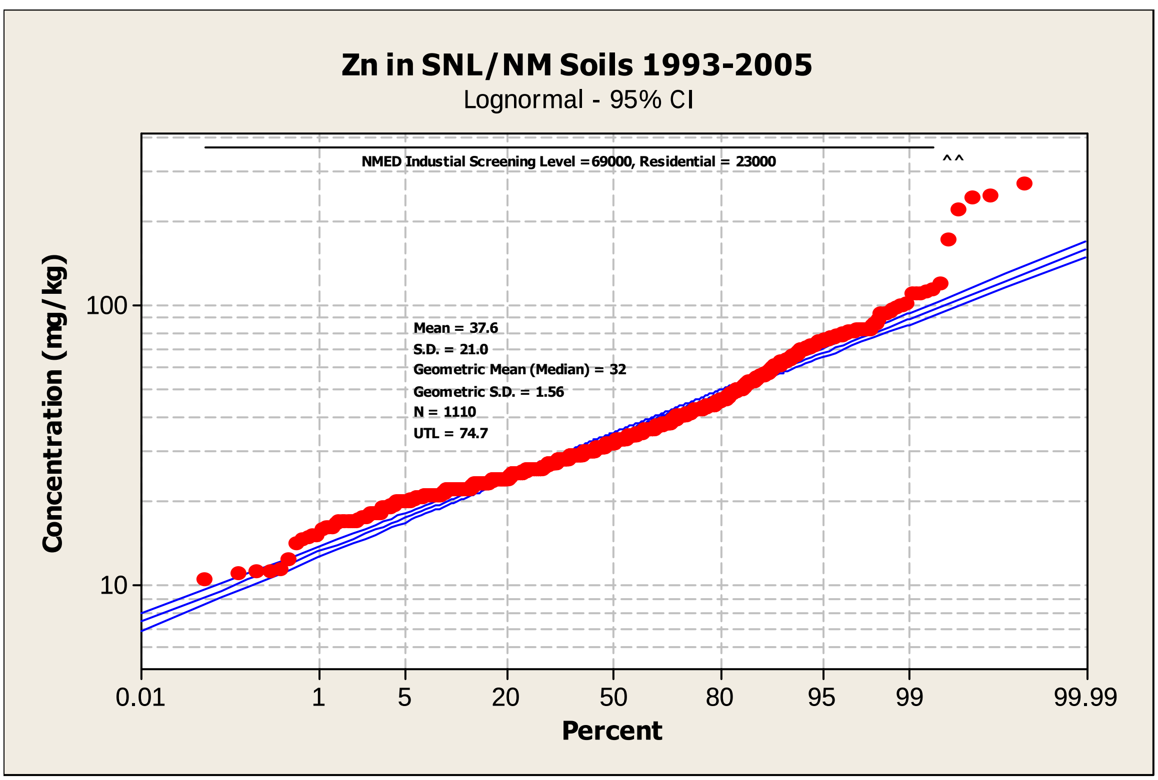


Se in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 1200, Residential = 380
Mean = 2.59
S.D. = 2.63
Geometric Mean (Median) = 0.73
Geometric S.D. = 6.8
N = 681
UTL = 7.2
Concentration (mg/kg)
10.0
1.0
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
Percent


Ti in SNL/NM Soils 1993-2005
Lognormal - 95% CI
No NMED Screening Values
Mean = 292
S.D. = 233
Geometric Mean (Median) = 230
Geometric S.D. = 1.96
N = 401
UTL = 703
Concentration (mg/kg)
1000
100
10
1
1
5
20
50
80
95
99
99.99
Percent


Tl in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 18, Residential = 6
Mean = 7.16
S.D. = 10.64
Geometric Mean (Median) = 2.36
Geometric S.D. = 5.5
N = 707
UTL = 25.9
Concentratin (mg/kg)
1000.0
100.0
10.0
1.0
0.1
1
5
20
50
80
95
99
99.99
Percent


V in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level = 1600, Residential = 530
Mean = 21.4
S.D. = 8.5
Geometric Mean (Median) = 20
Geometric S.D. = 1.44
N = 1110
UTL = 36.4
Concentration (mg/kg)
Percent


Zn in SNL/NM Soils 1993-2005
Lognormal - 95% CI
NMED Industial Screening Level =69000, Residential = 23000
Mean = 37.6
S.D. = 21.0
Geometric Mean (Median) = 32
Geometric S.D. = 1.56
N = 1110
UTL = 74.7
Concentration (mg/kg)
Percent

Distribution

1	MS1042	Mark Miller	10331
1	MS1042	Regina Deola	10331
1	MS0890	Heidi Herrera	10312
1	MS0491	Hans Oldewage	123451
1	MS0184	Karen Agogino	SSO
1	MS0184	Susan Lacy	SSO
2	MS9018	Central Technical Files	8945-1
2	MS0899	Technical Library	4536